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Effect of spacing and nutrient regimes on growth performances of *Dendrocalamus brandisii* (Munro) Kurz

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Abstract
The present investigation was carried out to assess the effect of spacing and nutrient regimes on the growth performance and relative growth rate of *Dendrocalamus brandisii* (Munro) Kurz under field conditions. A split plot design was adopted with two spacing regimes as main plot (M1: 4 m × 5 m and M2: 5 m × 5 m) and three nutrient regimes as sub plot (S1 - Optimum level of NPK, S2 - 25% more than optimum, S3 - 50% more than optimum). The study recorded significant variations in growth parameters such as number of culms per clump, internodal length, and culm hollowness over four years. Among nutrient treatments, S3 exhibited the highest values for average plant height, culm girth, and clump girth, suggesting the positive influence of balanced nutrient application. Similarly, wider spacing (M2) marginally improved growth attributes compared to M1, though differences were often non-significant. Internodal length and culm hollowness increased with age, while culm number decreased, indicating a shift from culm quantity to quality with time. The interaction of spacing and nutrients showed that M2S3 treatment produced the highest clump girth and culm hollowness, reflecting vigorous culm development. Relative Growth Rate (RGR) analysis further supported these findings. The highest RGR in average height (RGRAH) was observed under M2S3 (0.0278), while RGR in culm girth (RGRACG) showed minimal variation across treatments. The maximum RGR in clump girth (RGRCLG) was noted in M2S1, and RGR in shoot number (RGRAN) remained consistently negative, indicating reduction in new shoot emergence with increasing culm age. Thus, study highlights that appropriate spacing combined with optimum nutrient application significantly enhances productivity in *D. brandisii*. These findings may assist in optimizing management practices for large-scale bamboo cultivation aimed at biomass, shoot and culm production.

Keywords: Bamboo, growth performance, spacing and nutrient

Introduction
Bamboo is a fast-growing, perennial, and renewable resource of immense ecological and economic importance, often referred to as the “poor man’s timber.” Among the many bamboo species, *Dendrocalamus brandisii* (Munro) Kurz stands out due to its superior culm characteristics, edible shoots, and adaptability to a range of climatic conditions. Native to Southeast Asia and northeastern India, this species holds great promise for commercial cultivation, biomass production, and sustainable land use, particularly in tropical and subtropical regions. *Dendrocalamus brandisii* (Munro) Kurz, commonly known as Burma bamboo, is a robust, evergreen species characterized by its dense, tufted clumps and tall, straight, thornless culms. Its remarkable adaptability across a wide range of altitudes and soil types makes it highly suitable for agroforestry systems and ecological restoration projects. Recognized as one of the most valuable multipurpose bamboo species by the National Mission on Bamboo Applications (NMBA), Government of India, *D. brandisii* offers extensive utility in construction, handicrafts, and pulp fiber industries. Moreover, the species enhances soil health through its interaction with beneficial microbial communities and serves as a sustainable cultivation option in fallow and degraded lands, including abandoned paddy fields. In addition to its economic and ecological benefits, the shoots of *D. brandisii* are gaining popularity as a nutritious food source due to their low fat content, absence of residual toxins, and richness in dietary fiber, proteins, essential minerals, and vitamins.

The productivity and morphological attributes of bamboo are significantly influenced by silvicultural practices, among which spacing and nutrient management play a vital role. Optimal spacing regulates inter-culm competition for light, water, and nutrients, thereby influencing culm density, girth, and overall clump development (Singh *et al.*, 2020) [16]. Likewise, nutrient application enhances physiological functions such as photosynthesis, nutrient uptake, and biomass partitioning, ultimately improving growth and yield (Gopikrishna *et al.*, 2012) [3]. Despite its potential, there exists limited scientific literature on the effect of spacing and nutrient regimes on the growth dynamics of *D. brandisii*, especially under Indian field conditions. Furthermore, understanding the relative growth rates (RGR) of key biometric parameters such as height, culm girth, clump girth, and shoot number provides a deeper insight into the temporal growth behavior and resource allocation strategies of the species. Hence, the present study was undertaken to evaluate the effect of different spacing and nutrient treatments on the growth performance and relative growth rate of *D. brandisii*.

Materials and Methods

The study was conducted near to College of Forestry Ponnampet at farmers' field in Halligattu village, Ponnampet, Kodagu district, located in Hilly Zone at an altitude of 867 m above Mean Sea Level (MSL) with 12º 08' N latitude and 75º 55' E longitude. The experiment was conducted in an abandoned rice field year during the year 2022-23 to 2024-2025. The experimental plot area was 0.96 ha with a plot size of 123 m × 72 m. The experiment was laid out in Split plot design and replicated thrice with the two spacing as main plot treatments (M1 - 4.00 m × 5.00m and M2 - 5.00 m × 5.00 m.) with 225 plants per spacing and three nutrient regimes as subplot treatment. Based on the preliminary soil testing for NPK status and a thorough literature review, the optimum NPK requirement for bamboo was decided *i.e.,* 25 g of nitrogen, 9 g of phosphorus, and 25 g of potassium per plant. Accordingly, the following nutrient regimes were set as sub-plot treatments to assess the performance of Bamboo.

S1 - Optimum level of NPK (N:25 g plant^{-1}; P: 9 g plant^{-1}; K: 25 g plant^{-1})

S2 - 25% more than optimum (N:31.25 g plant^{-1}; P: 11.25 g plant^{-1}; K: 31.25 g plant^{-1})

S3 - 50% more than optimum (N:37.50 g plant^{-1}; P: 13.50 g plant^{-1}; K: 37.50 g plant^{-1})

Experimental observations

1. **Culm height (m):** The height of the culm was recorded using the measuring pole and will be expressed in meter.
2. **Culm diameter:** Individual culm diameter at breast height was measured in cm.
3. **Clump height (m):** The height of the clump has been recorded using the measuring pole and expressed in meters.
4. **Clump girth (m):** Clump girth was recorded at the breast height with the help of measuring tape.
5. **Clump girth (m) at breast height:** The spread of the clump measured around the clump at breast height and recorded in meters.
6. **Clump width (m):** The spread of clumps at two perpendicular sides, where one being its widest spread, was recorded using measuring tape. The mean of two was considered as clump width and expressed as meters.
7. **Number of culms per clump (#):** The number of culms present in the plant/clump was counted and recorded
8. **Internode length (cm):** Internode length is measured with the help of measuring tape in cm.
9. **Hollowness (cm):** Hollowness of bamboo were measured by using vernier calliper in cm. Three observations (one from base, second from middle and third from top) will be recorded to represent the whole culm.
10. **Relative growth rate (RGR):** Relative growth rate for height, average collar diameter and number of culms per clump were determined by using the formula

$$\text{Relative growth rate} = \frac{\text{Final observation} - \text{Initial observation}}{\text{Initial Observation}}$$

Results and Discussion

Spacing significantly influenced the growth parameters of *D. brandisii*. Wider spacing (M2) consistently outperformed closer spacing (M1) across all stages of growth. During the first year, plant height was marginally higher under M2 (6.77 m) compared to M1 (6.71 m), with the difference being statistically significant. Similar trends continued across 2-3 years and 3-4 years, with plant height in M2 (4.26 m and 2.55 m, respectively) exceeding M1 (4.03 m and 2.48 m), again showing significance. Culm girth also showed an increasing trend with wider spacing, with M2 recording higher girths in the first three years. The differences were significant in the 0-1, 1-2, and 3-4 year periods, but non-significant in the 2-3 year stage. Clump girth was significantly larger under M2 (5.344 m) than M1 (4.618 m), indicating that wider spacing encourages better overall clump development (Table 1).

Nutrient application had a pronounced impact on growth performance. Among the nutrient treatments, S3 (highest nutrient regime) recorded the tallest plants and the largest culm and clump girths at all growth stages. Plant height under S3 reached 7.31 m during the first year, which was significantly greater than S1 (6.43 m) and S2 (6.48 m). The trend of significant differences continued across the years. Culm girth followed a similar trend, with S3 showing maximum girth (18.16 cm in year 1) and the differences were statistically significant in the first two years. In the 2-3 year stage, the difference was not significant. Clump girth also increased with higher nutrient levels, with S3 recording the highest value (6.039 m), significantly surpassing S1 and S2 (Table 1).

The interaction effect between spacing and nutrient regimes was significant for several growth parameters. The M2S3 treatment combination (wider spacing + high nutrients) produced the maximum plant height (7.33 m), culm girth (18.38 cm), and clump girth (6.537 m). These values were significantly higher than the lowest observed under M1S1 (6.41 m, 17.05 cm, and 3.649 m, respectively) (Table 1). Significant interaction effects were noted in plant height during the 2-3 and 3-4 year stages, clump girth, and culm girth during the 2-3 year stage. However, plant height during the 0-1 year period and culm girth in the early years did not show significant interaction effects, as indicated by the non-significant CD values.

The present study demonstrated that both spacing and nutrient regimes significantly affect the growth performance of *Dendrocalamus brandisii*. Plants grown under wider spacing (M2) consistently exhibited greater plant height, culm girth, and clump girth than those under closer spacing (M1) (Table 1). This can be attributed to reduced competition for essential growth resources such as light, nutrients, and soil moisture, which facilitated better physiological and morphological development. These findings are consistent with earlier research that highlights the benefits of wider spacing in improving the growth and biomass yield of clump-forming bamboos and other agroforestry species (Singh *et al*., 2010; Kumari & Das, 2015) [17, 7]. Nutrient application also significantly enhanced the morphological traits of *D. brandisii*, particularly under the highest nutrient regime (S3). Increased nutrient availability, especially nitrogen, phosphorus, and potassium, likely supported more robust shoot elongation and culm development. The substantial increase in clump girth observed under S3 may be indicative of increased rhizome activity and shoot production, which is critical in clump-forming bamboo species. These observations align with previous studies that emphasize the importance of balanced nutrient supply in enhancing bamboo growth and productivity (Nirmala *et al*., 2007; Shi and Yang, 1992) [9, 12]. Significant interaction effects were also observed between spacing and nutrient regimes for several growth parameters. The M2S3 combination (wider spacing with higher nutrients) resulted in the highest values for plant height, culm girth, and clump girth, indicating a synergistic effect of adequate space and optimal nutrition. This combination appears to provide favorable conditions for maximum resource uptake and utilization, resulting in superior plant performance. On the other hand, the M1S1 treatment (closer spacing with low nutrients) consistently recorded the lowest growth, reaffirming the limitations of inadequate spacing and nutrient supply (Pandey *et al*., 2008) [10].

The number of different aged culms (0-1 to 3-4 years) did not show significant variation between spacing regimes (M1 and M2). However, among nutrient treatments, S3 recorded the highest number of culms across all age classes, with values of 9.93 (0-1 year), 6.42 (1-2 year), 4.70 (2-3 year), and 2.45 (3-4 year). The spacing × nutrient interaction showed that M1S3 and M2S3 both recorded the highest values (9.93 culms/clump) for 0-1-year-old culms, indicating a strong influence of nutrient levels over spacing in enhancing culm production (Table 2). Internodal length was not significantly influenced by spacing, but nutrient regimes showed marked differences. S3 exhibited the highest internodal lengths consistently across all four years (36.75 to 32.55 cm). Interaction effects revealed that M2S3 recorded the longest internodes (37.76 cm at 0-1 year), followed by M1S3 (35.73 cm), suggesting better nutrient uptake efficiency under S3 (Table 2). Hollowness was significantly influenced by both spacing and nutrient regimes. The lowest hollowness was recorded under M1 (7.62 mm at 0-1 year) while M2 exhibited higher hollowness values, particularly in older culms (22.64 mm at 3-4 years). Among nutrient regimes, S3 resulted in the highest hollowness (up to 22.48 mm), indicating a trend of increasing pith size with enhanced nutrient availability. The interaction effect showed that M2S3 consistently had the greatest hollowness across age classes, reaching up to 22.8 mm by 3-4 years (Table 2). The present study revealed significant variations in culm characteristics of *Dendrocalamus brandisii* influenced by different spacing and nutrient regimes. Notably, the nutrient regime S3 recorded superior performance across parameters such as internodal length, number of culms, and culm hollowness, particularly under wider spacing (M2). These results are consistent with earlier findings that appropriate nutrient supplementation enhances bamboo growth by improving soil fertility and promoting microbial activity (Singh & Naithani, 2007; Shanmughavel & Francis, 2001) [14, 11]. Internodal length was highest under S3 and wider spacing (M2), suggesting that better spacing allows sufficient light and nutrient availability for elongation of culms, a trend similarly reported by Kumar *et al*. (2015) [6] for *D. hamiltonii*. The number of different aged culms/clump also increased under nutrient-rich conditions, aligning with Singh, Singh, and Kishwan (2004) [13], who observed greater culm recruitment in nutrient-enriched plots. Additionally, culm hollowness increased with age and was more prominent under M2S3, which may be attributed to enhanced lignification and faster maturation due to higher nutrient uptake. The interaction effects between spacing and nutrient regimes were more pronounced in culm hollowness and internodal length compared to culm number. This supports the view of Banik (1993) [1] and Tewari (1992) [18] that site conditions and silvicultural practices like spacing and fertilization are critical for optimizing bamboo productivity. Although spacing alone did not significantly affect culm number or internode length, the synergy with nutrients, especially in M2S3, suggests that integrated management practices are essential for achieving sustainable biomass yields. Thus, adopting wider spacing with organic and inorganic nutrient inputs could be an effective cultivation strategy for *D. brandisii*, enhancing both productivity and culm quality. This aligns with the agroforestry objectives of optimizing resource use and maintaining long-term sustainability in bamboo plantations.

The relative growth rate (RGR) of *Dendrocalamus brandisii* under different spacing and nutrient regimes showed notable variation across growth parameters. Among the spacing treatments, M2 (wider spacing) recorded a slightly higher relative growth rate in average height (RGRAH: 0.017293) and clump girth (RGRACD: 0.134731) compared to M1 (0.016926 and 0.129060, respectively). The relative growth rate in average culm girth (RGRACG) was nearly similar in both spacing regimes (0.011647 in M1 and 0.011559 in M2). However, the relative growth rate in the average number of shoots (RGRAN) was negative across both spacings, indicating a declining trend (-0.24961 in M1 and -0.25002 in M2), possibly due to shoot mortality or self-thinning (Table 3). With respect to nutrient regimes, the enriched treatment S3 exhibited the highest RGRAH (0.017626), indicating a positive effect of nutrients on height growth. However, S1 (basic nutrient regime) showed the highest RGRACD (0.145972) and the lowest RGRACG (0.011256), while S2 had intermediate values (Table 3). Despite differences in nutrient levels, all regimes showed a consistent negative RGRAN, suggesting nutrient supplementation alone may not enhance shoot production. The combined effect of spacing and nutrients further highlighted interactions between treatments. The combination M2S3 resulted in the highest RGRAH (0.027817), indicating that wider spacing with enriched nutrients was most favorable for vertical growth. The highest RGRACD was observed under M2S1 (0.145853), while M2S2 showed the maximum RGRACG (0.011779) (Table 3). Similar to individual treatments, RGRAN remained negative across all combinations, with minimal variation (ranging from -0.24956 to -0.25013), implying that factors other than nutrient and spacing may be responsible for shoot number dynamics. Overall, these findings suggest that while spacing and nutrients significantly affect growth rate in height and girth, they have limited influence on shoot proliferation during the study period.

The observed variations in relative growth rates under different spacing and nutrient regimes are consistent with earlier studies highlighting the influence of management practices on bamboo growth. Wider spacing (M2) facilitated better light interception and reduced below-ground competition, leading to enhanced relative growth rates in height and clump girth. This is in agreement with the findings of Banik (1995) [2], who emphasized the role of wider spacing in promoting culm diameter and overall clump vigor in *Bambusa* and *Dendrocalamus* species. Nutrient application, particularly under enriched conditions (S3), significantly improved the height growth rate, which supports the observations by Nath *et al*. (2009) [8], who reported that macro-nutrient supplementation enhances vertical growth in bamboo by increasing metabolic activity and cell elongation. However, despite better growth in height and girth, a consistent negative relative growth rate in shoot number was observed, suggesting a phase of self-regulation or thinning typical of maturing bamboo clumps, as noted by Singh *et al*. (2002) [15].

The highest RGRAH recorded under M2S3 also highlights the synergistic effect of adequate space and nutrient availability on growth dynamics, a relationship similarly reported in *Dendrocalamus strictus* by Kumar *et al*. (2020) [5], where optimum nutrient management resulted in superior culm production and biomass accumulation.

Table 1: Growth performance of *Dendrocalamus brandisii* under different spacing and nutrient regimes

Treatments	Plant height (m)				Culm Girth (cm)				Clump Girth (m)
	0-1 year	1-2 year	2-3 year	3-4 year	0-1 year	1-2 year	2-3 year	3-4 year	
Spacing regimes									
M1	6.71	4.80	4.03	2.48	17.53	15.54	10.26	6.47	4.618
M2	6.77	5.04	4.26	2.55	17.86	16.58	10.34	6.61	5.344
S. Em (±)	0.0016	-	0.0082	0.0072	0.0068	0.0045	0.0346	0.0008	0.0158
CD (0.05)	0.0096	-	0.0497	0.0438	0.0417	0.0274	NS	0.0048	0.0963
Nutrient regimes									
S1	6.43	4.61	3.78	2.19	17.15	15.71	9.81	6.46	3.898
S2	6.48	4.94	4.25	2.50	17.77	16.07	10.42	6.57	5.005
S3	7.31	5.23	4.40	2.86	18.16	16.41	10.68	6.60	6.039
S. Em (±)	0.0073	-	0.0089	0.0164	0.0465	0.0324	0.0388	0.0041	0.0089
CD (0.05)	0.0238	-	0.0291	0.0534	0.1515	0.1057	0.1264	0.0133	0.0292
Spacing regimes × Nutrient regimes									
M1S1	6.41	4.56	3.56	2.02	17.05	15.24	9.86	6.43	3.649
M1S2	6.44	4.69	4.11	2.42	17.59	15.48	10.23	6.48	4.664
M1S3	7.29	5.16	4.42	3.02	17.93	15.91	10.7	6.51	5.541
M2S1	6.46	4.65	4.01	2.36	17.24	16.17	9.75	6.49	4.148
M2S2	6.52	5.18	4.4	2.59	17.95	16.66	10.61	6.65	5.347
M2S3	7.33	5.3	4.38	2.69	18.38	16.91	10.67	6.69	6.537
S. Em (±)	0.0103	-	0.0126	0.0232	0.0657	0.0458	0.0548	0.0058	0.0126
CD (0.05)	NS	-	0.0412	0.0755	NS	NS	0.1788	0.0188	0.0412

Table 2: Growth performance of *Dendrocalamus brandisii* under different spacing and nutrient regimes

Treatments	0-1 year	1-2 year	2-3 year	3-4 year	0-1 year	1-2 year	2-3 year	3-4 year	0-1 year	1-2 year	2-3 year	3-4 year
	Number of different aged culms/clump				Internodal length (cm)				Hollowness (mm)			
Spacing regimes												
M1	8.84 (2.97)	6.43 (2.54)	4.46 (2.11)	2.32 (1.52)	31.75	29.94	27.92	25.89	7.62	9.51	15.41	22.02
M2	8.86 (2.97)	6.32 (2.51)	4.48 (2.12)	2.45 (1.56)	32.69	30.43	28.35	25.73	9.22	12.79	17.12	22.64
S. Em (±)	0.00	0.02	0.00	0.02	0.3	0.27	0.3	0.61	0.05	0.06	0.01	0.01
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.3	0.33	0.05	0.05
Nutrient regimes												
S1	8.10 (2.846)	6.43 (2.535)	4.16 (2.038)	2.24 (1.495)	29.25	27.45	25.42	25.42	7.90	10.02	15.42	22.12
S2	8.53 (2.92)	6.28 (2.506)	4.56 (2.134)	2.46 (1.565)	30.66	28.53	26.43	26.43	8.38	11.15	16.58	22.40
S3	9.93 (3.151)	6.42 (2.533)	4.70 (2.167)	2.45 (1.566)	36.75	34.58	32.55	32.55	8.98	12.28	16.80	22.48
S. Em (±)	0.0014	0.0233	0.0017	0.0175	0.21	0.39	0.37	0.37	0.03	0.05	0.06	0.04
CD (0.05)	0.0044	NS	0.0054	0.0572	0.69	1.26	1.19	1.19	0.10	0.16	0.19	0.12
Spacing × Nutrient regimes												
M1S1	8.09 (2.84)	6.64 (2.57)	4.16 (2.04)	2.22 (1.49)	28.99	27.19	25.17	23.14	7.2	8.57	14.13	21.7
M1S2	8.51 (2.92)	6.27 (2.51)	4.54 (2.13)	2.33 (1.53)	30.52	28.73	26.71	24.71	7.5	9.1	16	22.2
M1S3	9.93 (3.15)	6.39 (2.53)	4.68 (2.16)	2.4 (1.55)	35.73	33.9	31.87	29.82	8.17	10.87	16.1	22.17
M2S1	8.11 (2.85)	6.23 (2.50)	4.15 (2.04)	2.25 (1.50)	29.5	27.7	25.67	23.33	8.6	11.47	16.7	22.53
M2S2	8.54 (2.92)	6.29 (2.51)	4.57 (2.14)	2.58 (1.61)	30.8	28.32	26.14	24.08	9.27	13.2	17.17	22.6
M2S3	9.93 (3.15)	6.44 (2.54)	4.72 (2.17)	2.51 (1.58)	37.76	35.27	33.24	29.77	9.8	13.7	17.5	22.8
S. Em (±)	0.00	0.03	0.00	0.02	0.2971	0.5448	0.5176	1.0565	0.04	0.07	0.08	0.05
CD (0.05)	NS	NS	NS	NS	0.9689	NS	NS	NS	0.14	0.23	0.27	0.17

*****Parenthetical values are square root transformed; CD-Critical Difference; NS- Non-Significant

Table 3: Relative growth rate in *Dendrocalamus brandisii* growth parameters under spacing treatment and nutrient regimes

Treatments	RGRAH	RGRACG	RGRCLG	RGRAN
Spacing regimes				
M1	0.016926	0.011647	0.12906	-0.24961
M2	0.017293	0.011559	0.134731	-0.25002
Nutrient regimes				
S1	0.01699	0.011256	0.145972	-0.24993
S2	0.015575	0.011548	0.14026	-0.25025
S3	0.017626	0.011533	0.116907	-0.25
Spacing regimes × Nutrient regimes				
M1S1	0.02568	0.011733	0.145519	-0.24979
M1S2	0.016308	0.011531	0.143439	-0.24956
M1S3	0.007994	0.011499	0.106299	-0.24983
M2S1	0.008066	0.01136	0.145853	-0.24957
M2S2	0.014393	0.011779	0.137086	-0.24986
M2S3	0.027817	0.011605	0.125899	-0.25013

RGRAH- Relative growth rate in Average Height; RGRACG- Relative growth rate in Average Culm Girth;
RGRACD- Relative growth rate in Average Clump Girth RGRAN- Relative growth rate in the Average number of shoot

Conclusion

The study revealed that both spacing and nutrient regimes significantly influenced the growth performance and relative growth rates of *Dendrocalamus brandisii*. Wider spacing (M2) combined with higher nutrient input (S3) consistently resulted in superior values for plant height, culm girth, clump girth and relative growth parameters, suggesting that reduced competition and adequate nutrient availability enhance overall clump development. Among all treatment combinations, M2S3 proved to be the most effective in maximizing growth and biomass accumulation. The findings highlight the importance of optimizing managemental practices such as spacing and fertilization to improve the productivity of bamboo plantations. Therefore, adopting the M2S3 treatment is recommended for sustainable and efficient cultivation of *D. brandisii*.

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